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Operating Characteristics of a High-Efficiency Pilot Scale Corn Distillers Grains Dryer

C. J. Bern, M. B. Pate, S. Shivvers

Abstract. *The rapidly expanding U.S. corn ethanol industry produces huge quantities of wet distillers grains and about 70% of this material is dried to 10% moisture. Drying this material requires about one-third of the energy used to operate a dry-grind corn ethanol plant. Tri-Phase Drying Technologies of Norwalk, Iowa has developed a rotary drum dryer which reclaims energy from the exhaust air stream. The objective of this research was to determine the energy requirement of the Tri-Phase dryer by pilot scale drying tests with wet distillers grains. Multiple tests of the pilot-scale dryer showed an energy input requirement of about 2890 kJ/kg (846 Btu/lb) of water removed when drying wet distillers grains from about 28% to 24% moisture. This is less than half the energy usually required for a drum dryer or a grain dryer. Use of this dryer design, scaled up to dry distillers grains at ethanol plants, has the potential for large energy savings for the corn ethanol industry.*

Keywords. *Distillers grains, Energy consumption, Drying.*

Dry grind corn ethanol production is increasing rapidly in the United States. In 2009, 97 million Mg (3.8 billion bu) of corn went into ethanol production (RFA, 2010), up nearly 18% from 2008 (1 Mg of corn is 1000 kg of corn at 15.5% moisture; one bushel of corn is 56 lb at 15.5% moisture; all moistures are % wet basis). This is 31% of U.S. corn production and about 12% of world corn production (U.S. Grains Council, 2010).

For each Mg (bu) of corn processed, about 420 L (2.8 gal) of ethanol and 312 kg (17.5 lb) of distillers grains at 10% moisture is produced (American Coalition for Ethanol, 2010). Distillers grains is a co-product containing most of the constituents of the original corn, except the starch used during the ethanol fermentation process. Most distillers grains are used as animal feed and, in the United States, about one-third is fed without drying (Staff, 2011).

Wet distillers grains is often a good fit for animal rations, but it deteriorates quickly during storage and it contains a large mass of water (Loy, 2008). Drying prolongs storage life and reduces shipping weight, but it is an expensive and energy-intensive process requiring specialized equipment. When wet distillers grains is dried to 10% moisture, about 2500 kg (140 lb) of water must be removed by drying per Mg (bu) of corn processed.

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Drying Wet Distillers Grains

Following discharge from a centrifuge, wet distillers grains is conveyed into a dryer for additional water removal. Most (over 87%) of dry grind ethanol plants use rotary dryers to dry distillers grains (Saunders and Rosentrater, 2009). In a rotary dryer, wet distillers grains is introduced into the upper end of a sloping, rotating drum. As the drum rotates, fins on the drum's inside wall lift and drop the drying distillers grains. In a direct system, heat is supplied by a direct-fired natural gas burner and hot gases flow through the drum along with the distillers grains. In an indirect system, steam tubes inside the drum supply heat. Drying air temperatures average 430°C, but some plants use air over 500°C. Dry distillers grains are discharged at about 90°C (Saunders and Rosentrater, 2009).

Energy for Drying Distillers Grains

Energy for drying is often calculated by adding the heat input rates to the dryer (usually natural gas which is burned, plus electrical energy to run electric motors) and then dividing this by the rate that water is being removed from a product. Rotary dryers typically require between 4600 and 9200 kJ/kg (1980 and 3960 Btu/lb) of water evaporated (Mujumdar, 2007). Heated air grain drying in column or bin dryers typically requires between 5500 and 7100 kJ/kg (2400 and 3100 Btu/lb) of water evaporated (Bern, 1998). In order to dry biological materials such as distillers grains, energy is needed to supply the latent heat of vaporization of the water, which is about 2440 kJ/kg (1050 Btu/lb). Additional energy is required due to dryer inefficiency and to evaporate bound water within the distillers grains particles.

Tri-Phase Rotary Drum Drying System

Tri-Phase Drying Technologies of Norwalk, Iowa has developed a rotary drum drying system for drying distillers grains and other products. This dryer includes a heat recovery process to reduce drying energy. The purpose of this research was to determine if the concept of the Tri-Phase drying

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system works by conducting instrumented tests of a pilot-scale model of the dryer drying wet distillers grains (WDG).

Flow Diagram

The Tri-Phase dryer heats wet product in a rotating drum and then removes moisture by counterflow aeration in a cooling/drying chamber (fig. 1). Exhaust air from the cooling/drying chamber is routed through a counterflow heat exchanger where it transfers latent and sensible heat to a fluid stream which supplies heat to the rotating drum. For this pilot-scale dryer, the fluid is water and additional heat is added to the fluid stream using an electric water heater. Within the rotating drum, the fluid stream flows through spiraled heating coils made of copper tubes mounted on the inner wall and transfers heat to the wet product. The hot, wet product is moved to the cooling/drying chamber which is aerated with ambient air. Cool, dry product exits from the cooling/drying chamber. Condensate and saturated exhaust air exit from the counterflow heat exchanger after transferring heat to the fluid. Figure 1 includes typical fluid and product temperatures through the dryer.

Schematic Diagram

Figure 2 is a schematic diagram of the pilot-scale dryer designed for a wet product input flow rate of 70 to 90 kg/h (150 to 200 lb/h). Wet product is placed in a hopper and enters the rotating drum through an airlock feeder. As the drum rotates at 3.4 rev/min, buckets on the inner wall continually lift wet product and drop it over the heating coils (fig. 3). An open transfer auger moves the wet product along the length of the drum and through check valves, and finally dumps it into the intake hopper of a flex auger which carries it to a hopper above the cooling/drying chamber (fig. 2). Product temperature reaches about 82°C (180°F) as it exits the rotary drum. Within the counterflow cooling/drying chamber, an external fan moves ambient air up through the bed of product at a rate of about 8.4 L/s (18 ft^3/min), which is an aeration rate of about 4.4 m^3/min/Mg (3.8 ft^3/min/volume bushel). This air then passes through a counterflow air-to-fluid heat exchanger where it gives up latent and sensible heat to the fluid. Condensate and saturated air are exhausted from the heat exchanger. Downward product flowrate is regulated by horizontal rotating metering plates at the bottom of the chamber turned by a motor above the chamber. The dried, cooled product exits the drying system through an airlock feeder under the cooling/drying chamber.

A pump continually circulates fluid at a rate of about 40 L/h (11 gal/h) from a reservoir, through the heat exchanger, and through an electrical resistance water heater where input heat is added to bring the fluid to a temperature of about 93°C (200°F). This fluid then flows through the spiral copper tubing in the rotating drum where it transfers heat to the wet product (fig. 2). Cooled fluid at about 29°C (85°F) then flows back to the reservoir. Water was the fluid used for all tests reported here.

Testing Materials and Methods

Several tests of the pilot scale drying system have been carried out. Results of three typical tests will be reported here.

Wet Distillers Grain

Wet distillers grain for testing was obtained from Little Sioux Corn Processors in Marcus, Iowa. This plant produces fuel ethanol using the dry-grind corn ethanol process. The wet distillers grains had completed one pass through a rotary drum dryer and did not have solubles added. Moisture content was in the range of 25% to 35%. Wet material was stored in a bin at the test site prior to testing. Distillers grains moisture contents were determined using 30-g samples and a hot-air, forced convection oven (3h, 105°C, AFIA 2007).

Instrumentation

The dryer was instrumented to log pertinent temperature (Campbell Scientific CR10X data logger, Campbell Scientific Logan, Utah), air pressure (Dwyer Magnehelic

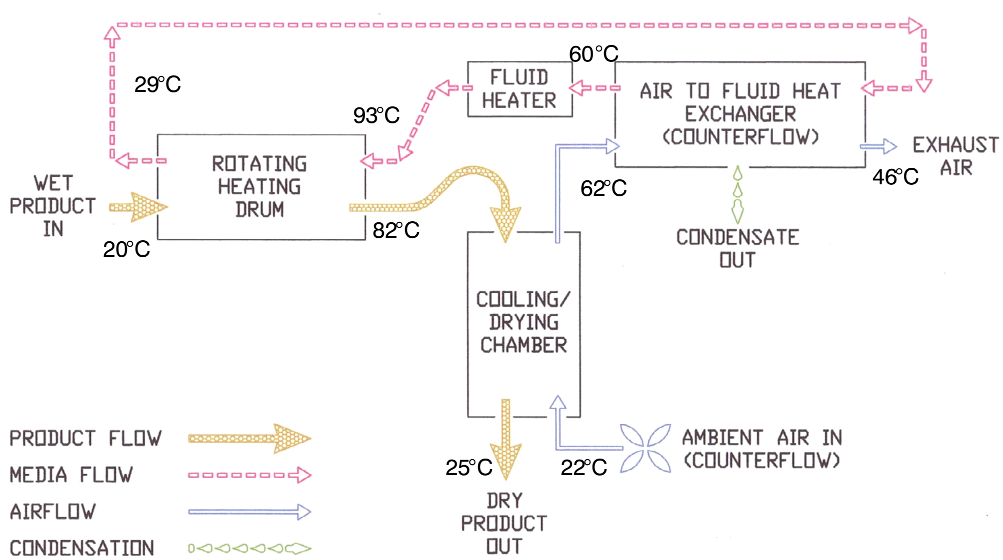

Figure 1. Flow diagram of Tri-Phase rotary-drum drying system.

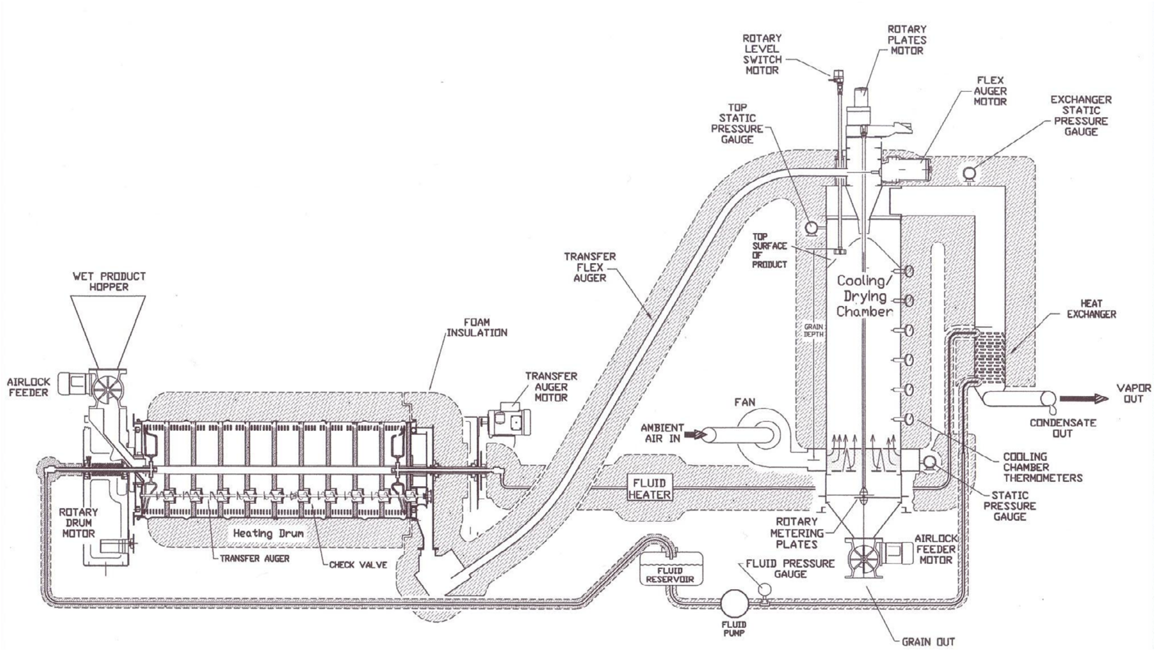

Figure 2. Schematic diagram of Tri-Phase pilot scale rotary drum drying system.

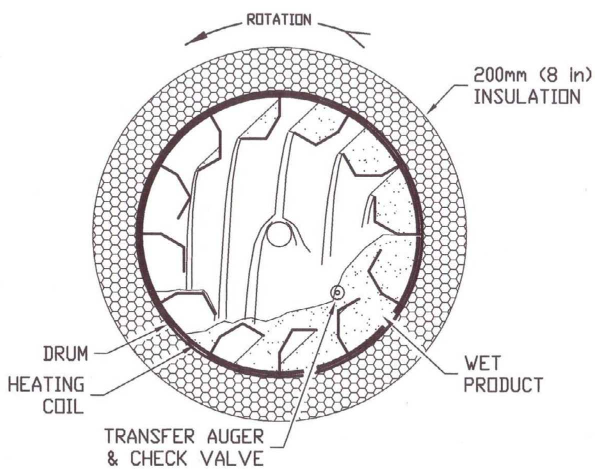

Figure 3. Cut-away end view of rotary drum.

model 2010, Dwyer Instruments, Michigan City, Ind.), airflow (Omega HHF91 volume-indicating thermo-anemometer, Omega Engineering, Inc, Stamford, Conn.), and electrical energy (Extech Instruments 380803 power analyzer/data logger Extech Instruments Corporation, Waltham, Mass.) values.

Testing Procedure

During testing, a worker manually maintained a supply of wet product in the hopper. A sample of wet product for moisture testing was drawn every 15 to 20 min. All dry product was caught in 20-L (5-gal) containers and weighed after it passed through the airlock feeder under the cooling/drying chamber. A 30-g sample for moisture testing was drawn from this material every 20 min. For analysis, output test data were matched to input test data drawn 146 min earlier. This accounts for product residence time in the dryer (60 min in the rotating drum, followed by 86 min in the cooling/drying chamber).

Results and Discussion

A summary of results from three tests is shown in table 1. For the three tests reported on, energy requirement averaged 2890 kJ/kg (846 Btu/lb) of water evaporated. This is about half of the lower end of the usual range reported for rotary dryers and grain dryers.

Issues Encountered during Testing

Initially, a variety of mechanical design issues were discovered and required remedial redesign of the apparatus; these involved air leaks, bearing failures, and air flow calibration issues. One issue was caking of wet distillers grains onto the heating coils inside the rotating drum. Caking is influenced by distillers grains moisture content and heating coil temperature. Because of the caking problem, incoming wet distillers grains moisture had to be kept at 30% or less.

Table 1. Near steady-state test data for the Shivvers rotary drum drying system.

Test Designation	A	B	C
Time of input data	11:11-11:41	11:55-12:25	3:30-4:30
Time of output data and energy usage	13:45-14:15	15:15-15:45	6:50-7:50
Input moisture (%)	26.5	29.3	29.3
Output product flowrate [kg/h (lb/h)]	62(136)	57(125)	57(126)
Output moisture (%)	21.9	25.0	25.0
Energy use [kJ/kg (Btu/lb)H_2O]	3130(916)	2850(833)	2700(790)

Energy Utilization Improvements

The maximum heating fluid temperature possible for this dryer was 93°C (200°F), which results in an 82°C (180°F) operating temperature. Design changes which will allow higher operating temperatures are planned. We anticipate that higher temperatures will improve energy efficiency, possibly allowing operation at 1700 kJ/kg (500 Btu/lb) of water evaporated.

Condensate Properties

Condensate leaving the heat exchanger was analyzed by the Environmental Engineering Research Lab at Iowa State University, with these results: Ammonia nitrogen: 0.32 mg/L, NO_3+NO_2 nitrogen: 0.01 mg/L, total Kjeldahl nitrogen: 1.73 mg/L, total phosphorus: 0.040 mg/L, pH: 4.33. The lethal concentration of ammonia for fish may be between 0.2 and 2.0, depending on pH, temperature, and species (USEPA, 1987). The limit of NO_3+NO_2 for human consumption is 10 mg/L (AWWA, 1990). The recommended level of nitrogen in estuaries to avoid algal blooms is 0.1 to 1 mg/L, while the phosphorus concentration is 0.01 to 0.1 mg/L. Higher concentrations of both will support less diversity (NOAA/EPA, 1988). The ideal range of pH for freshwater aquatic life is 6.5 to 9 (Smith, 1990). When this type of dryer is placed in service, condensate properties will need to be evaluated in light of the condensate disposal method selected.

Commercial Scale Up and Applications

The current test unit is a “Proof of Concept” pilot scale model specifically designed to demonstrate a rotary drum configuration application. Principles and processes demonstrated with this “Proof of Concept” model will be applied to a wide variety of industrial dryer types such as fluidized bed, disc, screw, conveyor, belt, tunnel, vertical column, and tray. Scaling will allow design for any desired throughput value.

Although this article is concerned with drying of distillers grains, a wide variety of particulates, powders, grains, discrete packages, sheets, sludges, and pastes may be dried in one or more physical configurations of the dryer types that may utilize the Tri-Phase heat recovery process.

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